CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-242
*** **SUPPLEMENT No.1** ***

FLEXURAL SLIP FAULTING NEAR PICO CANYON
Los Angeles County, California

by
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May 17, 1995

INTRODUCTION

This is a supplement to FER-242 (Treiman, 1994). This supplement has been prepared to respond to new data and interpretations received regarding the Preliminary Earthquake Fault Zone map for the Newhall 7½-minute quadrangle (CDMG, 1994). This new information (GeoSoils, 1995; Seward, 1995a,b,c) was received within the designated comment period (Calif. Public Resources Code, Div.2, Chapt.7.5, sec.2622(c); see Hart, 1994, appendix A). No additional comments were received at the public hearing held by the State Mining and Geology Board on February 22, 1995.

SUMMARY OF COMMENTS RECEIVED

New data and interpretations have been offered to try to disprove the interpretation of 1994 faulting across three adjacent landholdings (Figure 1). The two principal properties are a graded (but not developed) portion of Stevenson Ranch (Tract 33698) and undeveloped land to the north (Westridge, Vesting Tentative Tract 45433). A smaller affected area (Marblehead, Tract 44338) lies to the south. Surface fracturing, displacement and deformation are acknowledged to have occurred across these properties, however the consultants for the property owners (GeoSoils, 1995; Seward, 1995a,b,c) contend that the surface effects are related to unusually strong shaking and are not tectonic. New data on these issues include logs from extensive trenching and several borings. Refer to FER-242 (Treiman, 1994) for a more thorough description of the earthquake related surface features. The proposed Earthquake Fault Zone also extends across an undeveloped portion of Tentative Tract 49099 and into a developed part of Tract 33698 (southeast of McBean Parkway) however no surface fractures were observed within these properties.

Surface displacements at the Stevenson Ranch and Marblehead developments have been identified along faults labeled A through F (see Figure 1). The displacements are interpreted by the consultants to be the result of seismically triggered elastic rebound as a response to prior removal of up to 83 feet of bedrock from a ridgeline (GeoSoils, 1995; Seward, 1995b,c). They claim that the greatest amount of uplift coincided with the area of deepest removal. A post-earthquake survey (of part of the graded area only) showed that the ground between faults B/C and E/F had been elevated (relative to the adjacent terrain)

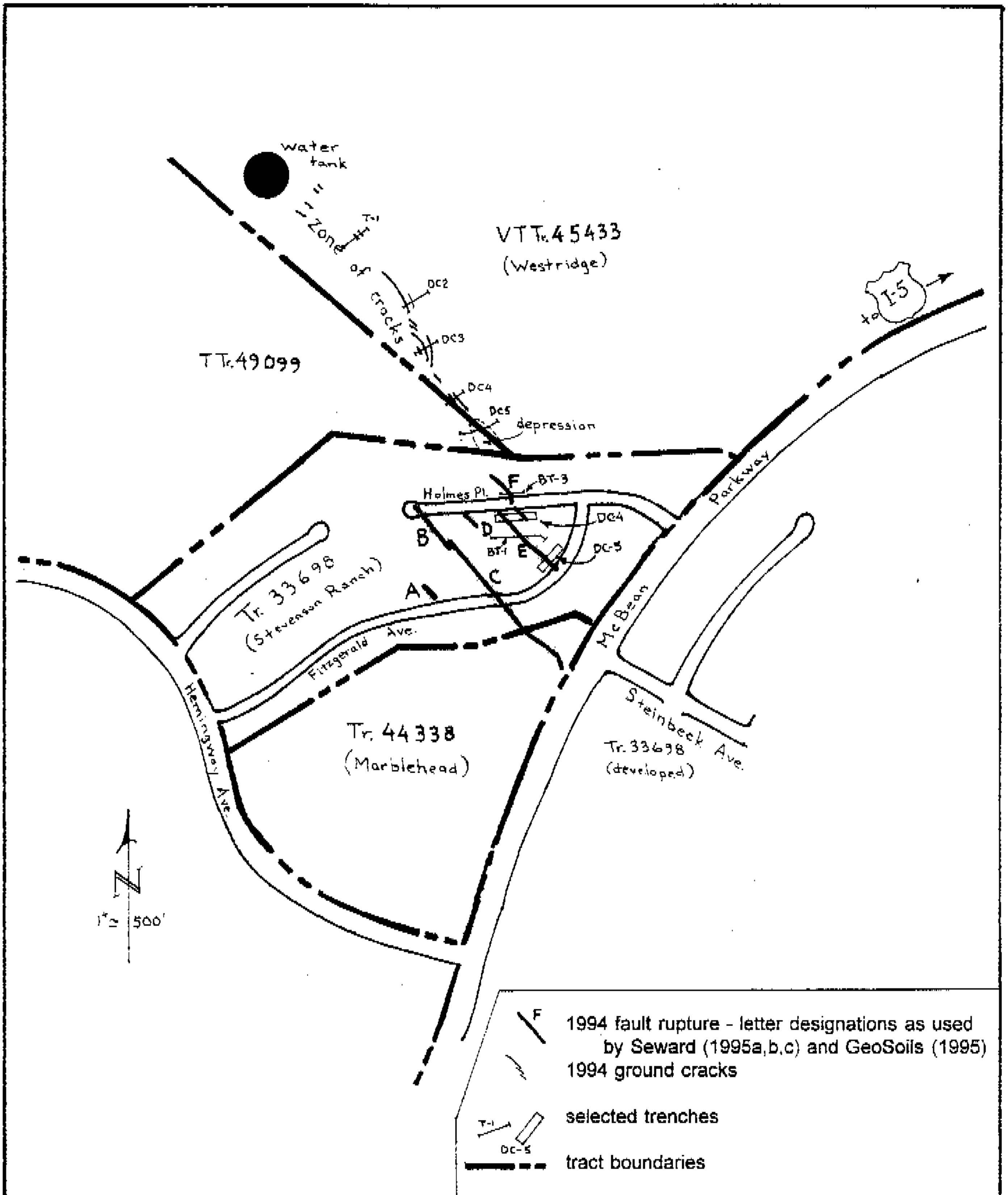

Figure 1 (FER-242, supp.#1) - Index map to tracts, faults and selected trenches, including and adjacent to Stevenson Ranch (Tract 33698). Faults recommended for zoning (A-F) are highlighted.

up to one foot (GeoSoils, 1995). Most of this relative uplift occurred near faults B/C and E/F although some uplift was distributed between and beyond these two bounding fault zones. Faults A, D and E were considered minor (with 2cm or less vertical offset) and no building setbacks were recommended. Faults B and C had the largest surface displacements (up to 19cm) and are closely related by a short stepover. Fault D is near the contact between Saugus Formation and the overlying mid- to late-Quaternary sands and gravels of the Pacoima Formation. Fault E is adjacent to what Seward (1995c) calls a zone of tensional deformation at the eastern margin of the principal uplift. Fault F, also near the eastern uplift boundary, is recognized by GeoSoils (1995) but is not discussed by Seward (1995c).

Seward (1995c) posits that a tensional zone (near faults E/F) is related to the contact between the Pacoima Formation and younger unconformable terrace deposits (Qt). He attributes the relatively downdropped area to the east to dynamic compaction of the Qt deposits. GeoSoils (1995 and Dave Sherman, personal communication) made clear that measured elevation changes were not absolute, but were relative to a local baseline.

GeoSoils (1995) conducted tests on samples from one trench in the Saugus Formation to try to demonstrate the rebound potential of the bedrock. They exposed the undisturbed rock samples to water and measured the expansion and load necessary to return the sample to its original volume. Based on this test, on two samples, they concluded that locked-in stress was equivalent to the overburden removed by grading and was sufficient to explain the uplift at the site.

Seward (1995b,c) argued that the displacement on the shears diminished with depth. For fault B/C he based this on the lesser displacement measured at the lower elevation on Tract 44338 (Marblehead) relative to the greater displacement within Tract 33698. For fault E he based this on the apparent truncation of the fault at depth in trenches DC-4 and DC-5.

Surface fracturing and lesser displacements in natural terrain to the north were interpreted to be the result of seismic shaking, lurching and settlement of part of the ridge flank (Seward, 1995a). Trenches showed that the bedding-normal surface fractures resulting from the Northridge earthquake died out within the depth of the trenches. Although a few of these fractures veered parallel to bedding, recent bedding-plane shearing could not be demonstrated. Some older fractures were observed that had no detectable displacement in this event and many of the new fractures did not have evidence of prior displacement.

A natural closed depression was interpreted as a non-tectonic feature within a landslide, rather than as evidence for repeated fault displacements, as proposed by Treiman (1994).

FIELD OBSERVATIONS

Many of the consultant's trenches were observed in the field[1] and independent observations were made. None of the borings were seen. Their trench logs are for the most part accurate and complete, although some differences may be noted between the logs of GeoSoils (1995) and Seward (1995a,b,c).

The displacement magnitude for Rupture E cited in the text (Seward, 1995c, p.10) is incorrect, however the correct displacement (1"-1.5"/2.5-4cm) is shown on his Plate VIII.

Trench BT-3 did expose a shear (fault F) that Seward (1995c) has not included in his log. However, this shear was shown by GeoSoils (1995).

Seward (1995c) logged only the south wall of Trench DC-4 from Stevenson Ranch. GeoSoils (1995) logged both walls. I am including my own log of the north wall of DC-4 (Figure 2). I did not have the opportunity to see the deeper backhoe trench within this bulldozer trench.

Trench T-1 on the Westridge property was originally excavated by Earth Systems Consultants (Patrick Boales, personal communication, 1994). Several older small-displacement (up to 7") northeast and southwest-dipping reverse and normal faults were exposed in their trench and observed by the writer. Minor surface fracturing occurred above one of the northeast-dipping faults during the Northridge earthquake. These older bedrock faults were not logged during subsequent re-excavation by Seward (1995a).

DISCUSSION AND CONCLUSIONS

There is no disagreement that surface ruptures, relative uplift and surface deformation occurred in the subject area during the Northridge earthquake. The only dispute is with regard to the rupture mechanism.

Fault B/C showed clear compressive reverse displacement. The thick zone of previously sheared bedrock demonstrated the repeatability of this deformation. The diminished surface displacement at the Marblehead project is just as likely related to a lateral change in slip as it is to a vertical change and does not affect the interpretation of this feature as a fault.

Seward (1995c, p.26) argues that the distress adjacent to Rupture E (and F) is tensional. However, his trench logs across this zone show no tension features. They do show reverse faults that cut across the bedding, bedding-plane shear surfaces associated with the January 1994 reverse surface displacements, and compressional folding. Ruptures E and F are reverse bedding-plane faults which require shortening rather than extension. Although some of the <u>surface</u> cracks may appear to be tensional the overall deformation in this zone is clearly compressional.

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[1] - Westridge - trenches DC-2, 3, 4 and 5, and T-1, 13, 14, 15, 16 and 17; Stevenson Ranch - trenches DC-1, 2, 3, 4 and 5, and BT-1, 3, 8, 9 and 10; Marblehead - T-1

Evident across the site is a northwest-trending concave-up monoclinal flexure (see also cross-sections by Seward, 1995c). This flexure is, in fact, the principal tectonic feature in this area and the various surface ruptures are a response to this folding. Its significance has only become apparent through the exposures in the recent trenching. The complex of interrelated folding and reverse faulting observed in the various trenches and borings (see, for example, DC-4 as shown in Figure 2) may be interpreted as bending-moment thrust faults and bedding-plane faults associated with the tightening of this fold (see Yeats, 1982a,b). The geologic record preserved in trench DC-4 shows repeated past compressional folding and faulting that has continued to affect the youngest geologic unit on site (Qt). This young deformation is also evident in DC-5, BT-1, BT-2, BT-3, BT-10 (Seward, 1995c) and to the north in DC-2, DC-4 and DC-5 (Seward, 1995a). The folding of Qt is particularly well-illustrated in BT-1 (Stevenson Ranch) where the dip of the bedding varies from 50° to horizontal within a distance of 30 feet (13m). The exposure at Holmes Place (Figure 2) also demonstrates the narrow zone of overturned bedding associated with the cross-cutting reverse faults. Steepening of the bedding and accompanying surface warping during the Northridge earthquake, that mirrors the past subsurface deformation, was evident at the intersection of McBean Parkway and Steinbeck Avenue, across Fitzgerald Avenue (Seward, 1995c, Plate VIII), and across Holmes Place (Figure 2). The progressive folding and unconformities between the Saugus Formation (TQs), Pacoima Formation (Qp) and terrace deposits (Qt) also document the long-term activity of this zone of flexure. Seward (1995c, p.49) recognizes that this folding has been a continuing process "for at least several hundred thousand years."

With tightening of the fold it is natural that the core of the fold will be squeezed and forced upward and northeastward. This has resulted in the bending-moment thrust faults and small folds on the east as well as the bedding-plane back-thrusts of Ruptures A through F. The faults within this active fold may well be shallowly rooted and probably are not seismogenic. Bending-moment faults generally diminish in slip as they approach the zone of neutral stress within the fold. Nevertheless, fault rupture (and significant surface deformation) can be expected to recur in the future in this linear zone of flexure. The location of these ruptures is not directly related to the formational contacts. The TQS/Qp contact is only associated with one of the lesser ruptures (D). The Qp/Qt contact is unlikely to control this type of rupture since the materials are so similar. Dynamic compaction of the Qt <u>may</u> have occurred but this phenomenon is certainly not proven by the post-earthquake uplift survey which showed only <u>relative</u>, not absolute, elevation changes. In fact, any coincidence between the contacts and the deformation is probably because this zone of flexure (and uptilting to the southwest) is a natural boundary for the deposition of the valley-filling alluvium (Qp and Qt).

The axis of the north-northwest trending linear zone of flexure appears to be slightly oblique to the northwest strike of the bedding causing the warp to be expressed in higher parts of the stratigraphic section as we follow it to the northwest (from McBean Parkway to DC-2 on the Westridge project). This apparent obliquity may also be a result of a southwest dipping axial plane projected onto the higher topographic elevations to the north. This zone of flexure may be the northeastern limit of tightening related to compression and uplift of

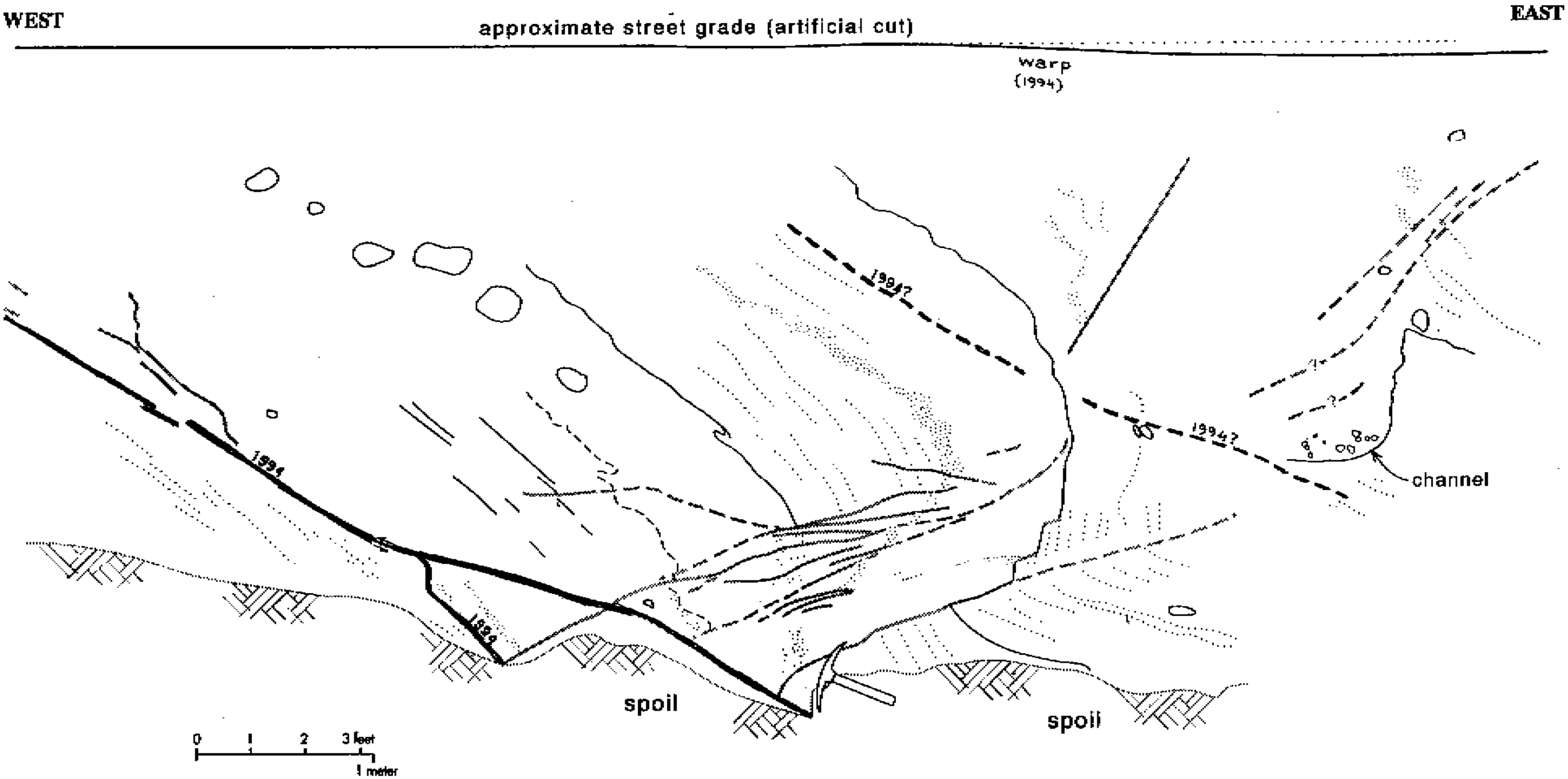

Figure 2 (FER-242, supp.#1) - Sketch log of trench exposure (DC-4, Stevenson Ranch) south of Holmes Place. North wall of trench is shown. Trench depth is approximately 3.5m below street level. Bedrock is Pacoima (?) Formation. Multiple low-angle bending-moment thrust faults document a history of previous displacements that have folded the coarse sediments of the Pacoima (?) Formation. 1994 rupture surface (fault E), in the left portion of this sketch, offsets the southwest-dipping thrust surfaces. Rupture follows bedding-planes up to the left, from 2.5m depth to the surface. Queried 1994 rupture in upper central portion of sketch may be southern end of fault F. Surface warping in 1994 mirrored the older folding and was probably accompanied by incremental growth of this structure. (drawn from a 35mm slide)

the Santa Susana Mountains, or merely a locally active fold axis near the margin of the Santa Susana Mountains anticlinorium. It may also be a fault propagation fold related to an unmapped thrust fault at depth or possibly even the tip of the Northridge event. Indeed, Seward (1995a,b,c, p.4) acknowledges that the site is along the northern margin of the projection of the fault-plane solution for the Northridge earthquake.

Rebound, although possible, does not appear to be a wholly adequate (nor necessary) explanation for the localized uplift and differential displacements that occurred at the Stevenson Ranch and Marblehead developments. Although maximum relative uplift does coincide somewhat with maximum cut areas, the greatest **fault displacement** does not. Up to 19cm of vertical displacement occurred along fault C adjacent to where only 40' to 50' of rock was removed whereas fault displacement diminished to 8cm or less adjacent to the maximum (83') removal area. Reference to a reconnaissance of earthquake damage and grading plans for the entire tract (GeoSoils, 1994) shows that there were several other ridges in this tract with 80 to 100 foot deep cuts, yet no similar deformation was reported. If uplift were due to elastic rebound it should have occurred as well in other larger cuts in the development. Instead uplift was restricted to the axial area of a well defined monoclinal warp. Tests performed by GeoSoils (1995, p.20) on two samples from the uplift area document the swell potential upon wetting of expansive bedrock of the Saugus Formation. The tests do not demonstrate locked-in stress or rebound potential, nor are they necessarily representative of the other bedrock types underlying much of the uplift area. GeoSoils (1995,p.22) also attempted to compare the effects at this site to "bedding-plane slippage after the San Fernando Earthquake that was confined to a cut-excavated ridge" as described by Barrows (1975). Barrows (1975, p.103) stated "A sharply defined scarp developed only over a graded bedrock surface for a length of 45 m (150 feet) although surface breakage could be traced for almost 245 m (800 feet) along this fault". Rather than describing "slippage ... confined to a cut-excavated ridge" Barrows has described a fault that was only sharply expressed in the cut area but nevertheless extended beyond. This is similar to what we have observed at Stevenson Ranch.

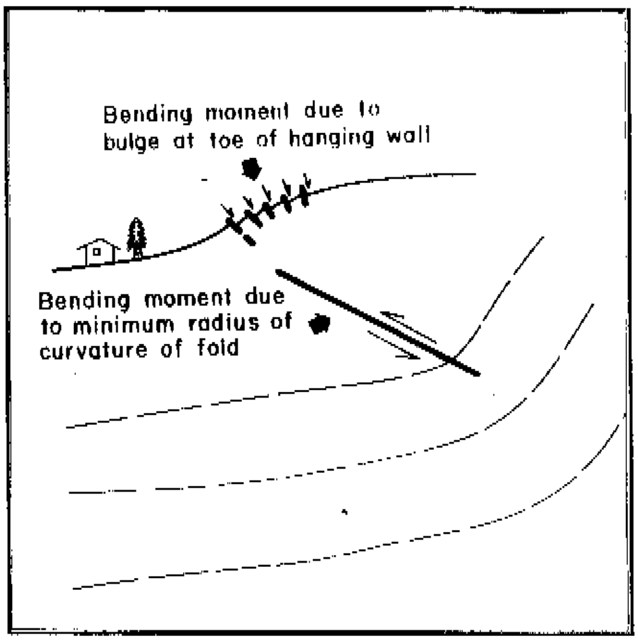

Figure 3 - Illustration of bending-moment thrust fault and related normal faults (modified from Yeats, 1982b, Figure 2).

Trenching to the north of Stevenson Ranch (Westridge; Seward, 1995a) has shown the continuation of the zone of folding and compression. The surface fractures that occurred on the Westridge project during the Northridge earthquake could not be observed to be related to faulting at depth and had no clear evidence of prior movements. Although the surface fracturing in this zone is perhaps more simply explained as a shaking phenomenon than as a tectonic one, its correspondence to the zone of folding is remarkable. The active flexure is probably the underlying cause of the outwardly tensional surface fracturing. This association is supported by the linear *en echelon* nature of the fracture zone. Figure 3 illustrates how normal faulting may occur in association with bending-moment thrust faulting. These relations are similar to those shown by Seward (1995a) in trench DC-4 on the Westridge property.

Seward (1995a) has shown that the closed depression cannot be entirely accounted for by tectonic forces and therefore is not evidence, in itself, for repeated Holocene displacement in this zone. The most plausible explanation presented for the closed depression is that it is an old drainage segment that has been translated downhill within an old landslide. However, the compressive reverse faulting evident in DC-5 may have accentuated this feature. Regardless, the geology preserved in this landslide mass demonstrates the presence of the zone of flexure, and the folding process is probably continuing beneath the landslide.

RECOMMENDATIONS

The proposed zoning (CDMG, 1994) should be reduced to include only the well-defined faulting within the graded area (Figure 1). Within the graded areas of Stevenson Ranch and the Marblehead development clear co-seismic faulting has occurred along shears with ample evidence of prior displacements (Ruptures A-F). The area recommended for zoning also includes a narrow well-defined active fold or flexure with internal thrust faulting across bedding. Tectonically related surface warping is so narrowly constrained that it may damage a structure built across it. Structures should be set-back from the bending-moment thrust faults within the core of the concave-up fold as well as from bedding-plane faults within the Earthquake Fault Zone boundaries.

Report reviewed and approved. William A. Bryant May 24, 1995

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